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TE[illegible] OF THE NEO-KEN DC TRACTION MOTOR (K-MOTOR)

by

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April 1983

Prepared for the
Transportation Development Centre
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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 4834 E	TDC 4867	

4. Title and Subtitle	5. Report Date
Test of the Neo-Ken DC Traction Motor (K-Motor)	August 1983
	6. Performing Organization Report No.

7. Author(s)	8. Transport Canada File No.
W. M. Mizera	D1465-399

9. Performing Organization Name and Address	10. DSS File No.
TranSyt Canada Inc. 2 Sheppard Avenue East, Suite 1900 North York, Ontario M2N 5Y7	11. DSS or Transport Canada Contract No. 4867

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre 1000 Sherbrooke Street West, Suite 2421 Montreal, Quebec H3A 2R3	Final -January-April, 1983
	14. Sponsoring Agency Code

15. Supplementary Notes	16. TDC Project Officer
	J. Morgan

17. Abstract

This report describes the initial testing and results of a new type of switched-reluctance DC motor that is intended for low speed, controllable torque applications. This motor is closely associated with its control system and the two should be considered one entity.

Only a fraction of the motor design capacity was achieved as the tests were constrained by the shortcomings in the power supply system and the loading method. The test results and the potential power, speed range and torque control of the motor as well as its low manufacturing costs, contribute to the recommendations that further tests be conducted, including the parallel pole coil connections. The inertial load method and a power supply of adequate capability should be used, along with an advance angle optimization for various speeds.

18. Key Words	19. Distribution Statement
Switched-reluctance Motor, Low Speed DC Motor, Testing	Limited number of copies available from sponsoring agency

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	56	Nil

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 4834 E	CDT 4867	

4. Titre et sous-titre	5. Date du rapport
Test of the Neo-Ken DC Traction Motor (K-Motor)	août 1983
	6. N° du rapport de l'organisme exécutant

7. Auteur(s)	8. N° de dossier Transports Canada
W. M. Mizera	D1465-399

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
TranSyt Canada Inc. 2 Sheppard Avenue East, Suite 1900 North York, Ontario M2N 5Y7	11. N° de contrat — ASC ou Transports Canada 4867

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transports 1000 ouest, rue Sherbrooke, Suite 2421 Montréal, Québec H3A 2R3	Final; janvier-avril 1983
	14. Code de l'organisme parrain

15. Remarques additionnelles	16. Agent de projet — CDT
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17. Résumé

Ce rapport décrit les essais et les résultats préliminaires concernant un type nouveau de moteur courant continu à réluctance variable, conçu pour faibles régimes et conditions d'utilisation à couple variable. Le moteur et sa commande formant un tout, ils doivent être considérés ensemble.

Les essais n'ont porté que sur une fraction de la puissance théorique du moteur, vu les faiblesses de l'alimentation et de la méthode de mise en charge. Néanmoins, des essais plus poussés sont recommandés au vu des résultats, de la puissance théorique, de la plage des vitesses, de la possibilité de réglage du couple et du faible coût de fabrication du moteur. Les essais devront porter aussi sur les connexions des bobinages polaires parallèles. La méthode de mise en charge par accélération d'une masse ainsi qu'une source d'alimentation adéquate devraient être essayées, de même que l'optimalisation de l'angle de décalage en avant du champ d'excitation aux différentes vitesses.

18. Mots-clés	19. Diffusion
Moteur à réluctance variable. Moteur c.c. à basse vitesse de rotation. Essai de moteur électriques.	Le CDT dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non-classifiée	non-classifiée	56	nil

ACKNOWLEDGEMENTS

The author would like to express his gratitude for the advice and invaluable assistance of Mr. Rudolf Kenwell, the K-Motor inventor, of Neo-Ken Electrical Industries Ltd., in Edmonton.

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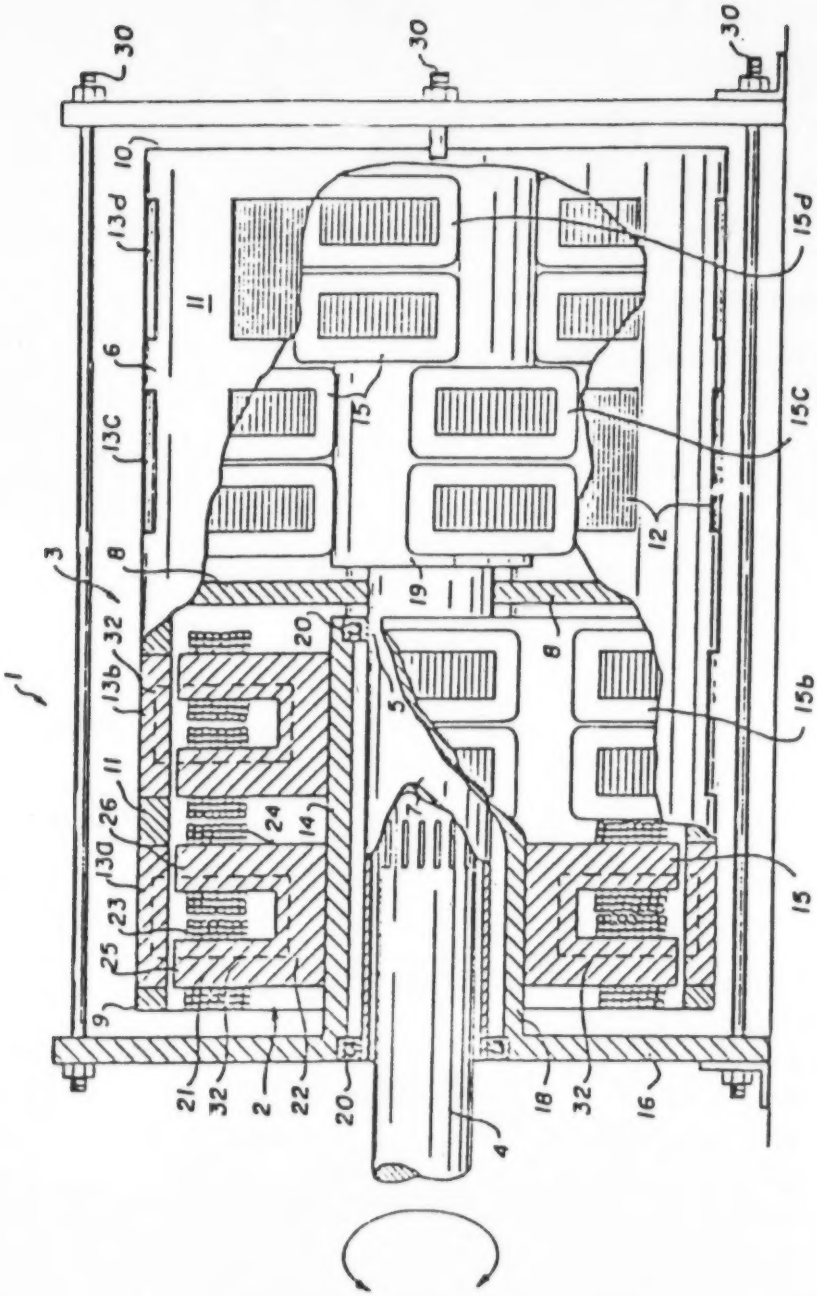

SIDE VIEW OF THE K-MOTOR

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1. INTRODUCTION

TranSyt Canada Inc. undertook to test a novel patented switched-reluctance electric drive in conjunction with the University of Toronto for the Transportation Development Centre in Montreal.

Mr. Rudolf Kenwell of Edmonton, the inventor of the motor, was present in Toronto at the initiation and calibration stage of testing, providing his indispensable instructions and advice.

The testing period was longer than intended but still as short as possible, considering the equipment and the concurrent work load on the part of the Electrical Department of the University of Toronto.

This institution was chosen to test the K-motor on the strength of their assurances about their capability and equipment.

In January 1983, a preliminary assessment was made by the group of Prof. Dewan, indicating that on the basis of principles involved in K-motor operation and its external features, the expectations of the motor's performance advantage are minimal.

The subsequent tests, in March 1983, seemed to confirm this point of view. Fortunately, the professional consultations, based on the knowledge of the tested system, indicated that some of the technical and attitudinized test conditions may have been responsible for the University assessment and, consequently, it became apparent that a further round of tests is to be recommended.

The K-motor would then be given a chance to be proven a feasible drive system for electric road and rail vehicles, as well as other motor driven machinery, in a way relatively free of the testing equipment limitations, within a more positive user environment.

The University of Toronto part of this report is published here as Appendix "A" in its unaltered form and should be referred to throughout the report.

The TranSyt Canada part precedes it to give the reader a chance to gain a better insight into the subject and give it a subjective evaluation.

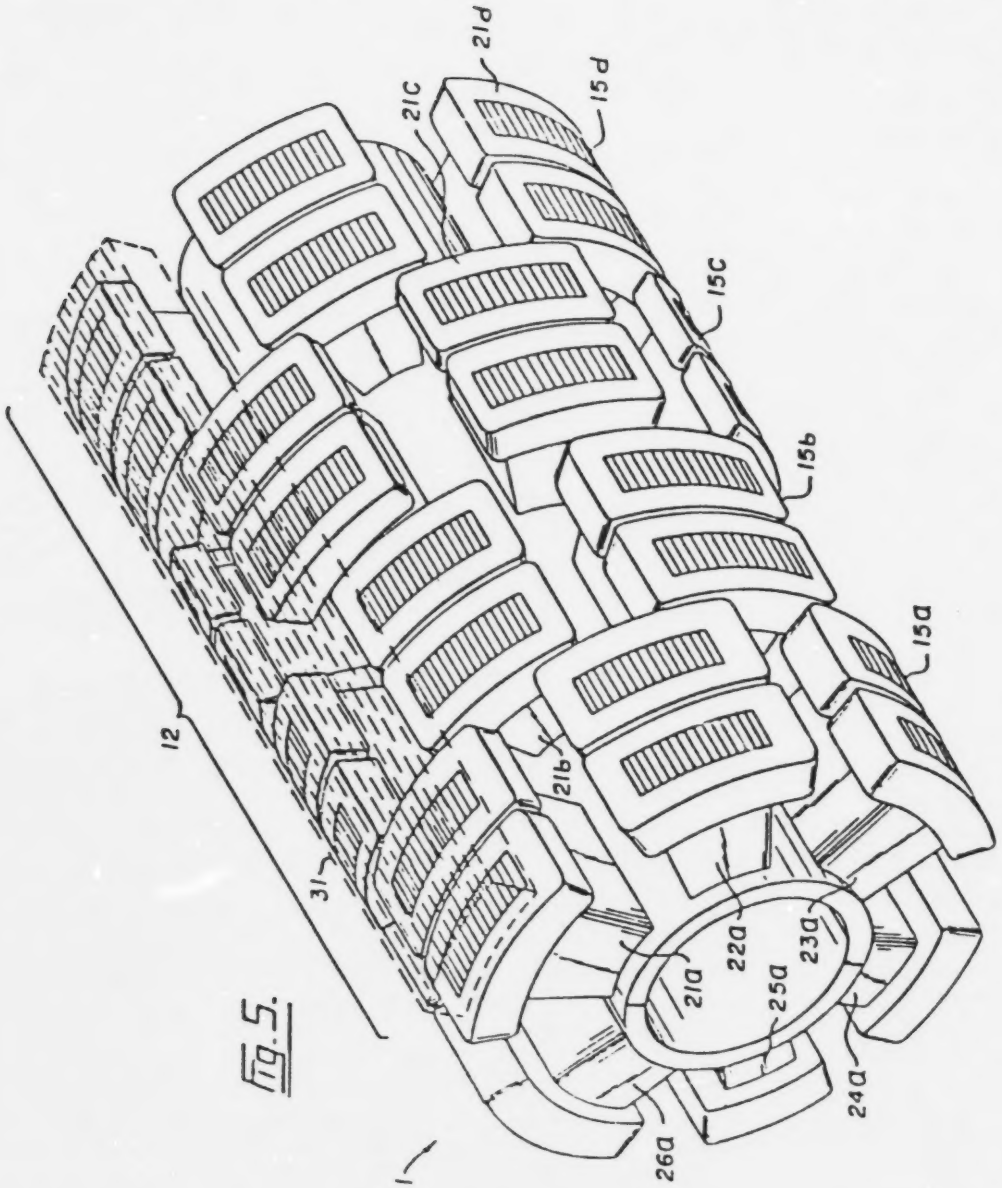

Fig. 5.

AN ISOMETRIC VIEW OF THE K-MOTOR

2. K-MOTOR - GENERAL FEATURES

The design objective of the K-motor is to improve the systems within which it is used.

It is a member of the switched-reluctance family of motors that are now able to make use of the advances that occurred in the field of power control components.

It should be borne in mind that the test results given here are from a prototype machine, built to prove the principles such that they may be used as a reference.

From this reference, a further commercial design may be undertaken to create a product line range of K-motors to suit a variety of user requirements.

The salient features of the K-motor are as follows:

a) Direct and full control over switching of individual poles by means of power transistors; variable torque - variable rpm operation; easy incorporation of motoring and braking modes.

b) Good total efficiency, the motor contains its own power conditioning equipment hence the necessity to consider the total system in all evaluations.

c) A high torque produced at low rpm suits well the over-load work conditions and the direct drive applications, eliminating gearboxes and power transmission shafts. Good examples of use are electric cars and rail transportation.

d) K-motor provides brushless operation, increasing the reliability of the systems it is incorporated into, and vastly decreasing the electromagnetic radiation caused by commutator and brushes.

e) A multitude of poles in the motor provides a smooth operation with only minimal torque ripple. That further enhances its advantages as a traction motor.

f) In the inside-out configuration, the K-motor provides an inherently improved torque output as the air gap is farther from the axis of rotation. The air gap width can be minimal at zero speed and it is increasing as the outside (no electric parts) is accelerating.

g) The coils on the inside stator do not experience any centrifugal forces and are easily individually replaceable due to their separate connections.

h) Excellent dynamic and static ventilation abilities of the K-motor increase significantly its capabilities, as it is the thermal considerations that limit the performance of any enclosed, conventional machine.

i) The lower component and manufacturing costs of the K-motor contribute to its attractiveness as do its decreased maintenance and repair costs. The K-motor also yields more easily to design variations, making it an ideal, not compromised, drive for most sophisticated applications.

By way of example, in a general rail transportation application, the weight savings, by elimination of gearboxes, shafts and reduction of the bogie weight, are estimated to be in the order of 30% of bogie weight. The standard traction motor control functions may be easily incorporated: overcurrent protection, wheel slip/slide protection, pre-programmed acceleration/deceleration curves, dynamic or regenerative braking, operator misuse protection, negative fail-safe protection, etc. The motor control would also interact easily with the communications and telemetry digital equipment.

On the strength of its design, manufacturing costs, system efficiency and controllability, the re-worked K-motor constitutes the best overall solution to the electric traction drive problem.

3. TEST DESCRIPTION AND DISCUSSION

The tests of the K-motor by the University of Toronto were seriously compromised by the inadequacy of the equipment used and the fact that the tests were conducted on an "as is" basis. No effort was made to improve the motor performance by means of the relatively simple advance adjustments provided. In addition, university staff did not take advantage of any assistance offered to them.

The compromised agreement (Appendix A of the University Report) resulting from this situation reflects the minimal expectations and the need to obtain some results, however qualified, rather than a statement of test objectives.

The test results given in Appendix A reflect the limited test conditions and may only be used for qualitative purposes. Acknowledging the conditions for testing, the following tendencies were observed:

- the torque falling off with speed (using constant power operation)
- the torque peak at the optimum pole advance angle
- the efficiency holding on a relatively flat level through most of the speed range (small iron losses).

The observed output voltage and current waveforms are partially a result of significant input ripple and do not necessarily reflect the true waveforms produced.

In light of the above limitations beyond our control, we cannot accept statements 2 and 3 of Appendix A (page 7.1) and only partially, statement 1 of the same page.

The potential advantages of a low speed, high torque DC machine far outweigh the limitation of its current, experimental embodiment, the adversely affected recommendations and the natural reluctance of the field to novel solutions.

4. QUALIFICATIONS AND RECOMMENDATIONS

The supply voltage for the K-motor can be higher than the voltage used if a "stiffer" power supply is used, contributing to the current increase and, subsequently, to the higher torque developed.

The pole advance angle was not optimized for a continuously changing speed and that resulted in a single torque peak at about 400 rpm.

The measurements of a torque at zero speed can be taken if a different, insensitive to speed, method of motor braking is used in the next round of testing.

The efficiency measured is the combined efficiency of the control system and the motor, ranging (in standard DC motor applications) from 50% to 65% under full load and, therefore, being comparable to the K-motor system efficiencies for speeds corresponding to the optimum advance or no-advance.

The K-motor action can be improved, according to the inventor, by switching from series to parallel windings within each pole, increasing the current drawn and decreasing the pole inductance, thus increasing the system efficiency.

According to the inventor, an approximately 20% current ripple on the power supply may have deteriorated the K-motor system performance.

The situation would be improved by using a "clean" DC power supply for future tests.

The torque-per-volume performance parameter can be vastly improved, not only by increasing torque but by easily decreasing the motor volume. The K-motor, in its present embodiment, is not meant to be volume-saving and will probably continue to be so.

TranSyt Canada Inc. recommends further testing, taking into consideration the above points. This should provide an opportunity to show the performance of the K-motor, unqualified and uncompromised by the less than perfect testing conditions that were used for the present developmental model. The pole energization advance must be optimized for any given speed and made to change continuously, thus ensuring a closer to optimum operation.

We also recommend that the search be continued for the power switching transistors able to handle higher currents, being closer to the current-carrying capabilities of the copper windings. The pole windings of the prototype motor are rated at 600 amps per phase or 1200 amps peak for two phases, but were tested out at only 290 amps total at 375 rpm.

5. FUTURE DEVELOPMENTS

TranSyt Canada recommends that further, more comprehensive testing of the K-motor be undertaken.

The tests are to comprise a denser measurement grid (at least 20 motor speeds between 0 and 1000 rpm) and are to use the rotating inertia load method, whereby the torque available at the motor shaft manifests itself in a momentary acceleration of a large rotating mass of a precisely known (calibration) mass inertia moment. The torque available is directly proportional to that acceleration, once the minute corrections for friction and aerodynamic drag on the load are added.

The duration of the tests is approximately 40 - 80 seconds and the time increment between the readings is small enough that the error in acceleration calculations is negligible.

The numerical differentiation of the motor speed will be performed digitally to further decrease the momentary acceleration error. An optimum energization advance angle is to be established for each motor speed and the performance of the motor will be established on the optimized basis. Following this, an automatic advance device should be designed and constructed.

The development of the switched-reluctance DC machines is rapidly gaining prominence in the laboratories and research centres around the world. What makes this possible over the crude, electromechanically switched machines of the past, that were considered the "dead end" in the electrical machines research, are the dramatic advances of the solid-state power electronics, that enable the switching of large currents at the high speeds necessary to operate a multi-pole reluctance machine.

At the present time, switched-reluctance machines evolved to exhibit a usually superior overall efficiency, particularly under partial load conditions.

They also exhibit an excellent controllability over their whole range of operation speeds, an excellent power-torque/volume ratio and high reliability. They also offer a control system that is considerably less complex than those of AC drive systems.

Controllability reflects the degrees of dynamic response of a machine, its speed range, stability, accuracy, regulation, smoothness of torque output, etc. Reliability is a reflection of the nature and extent of the electronics, including the protection and security features, the necessary level of maintenance (particularly low for a brushless switched-reluctance machine) and the suitability for hazardous and dirty environments.

The electronic controls of switched-reluctance machines enhance their use for all modes of operation, including dynamic or regenerative braking, which further contribute to their versatility. The K-motor also enjoys the advantage of having an outside rotor, facilitating its cooling and improving its performance at the cost of a slightly larger total volume.

The cost factor should also be taken into account in any system evaluation. Here, the advantage of switched-reluctance machines is clear: the use of identical and individually mounted coils, low tooling and initial investment costs and their particular amenability to a production line (vs. batch) assembly, contribute to their high cost attractiveness.

Switched-reluctance drives have been built in a variety of sizes (from 10 W at 10,000 rpm to 50 kW at 750 rpm). Their features make them ideally suitable for a multitude of applications. Some of these are in process industry machinery, various fans and pumps, servomechanisms, lifts and cranes, mixing and blending devices, printing, packaging, sewing, washing and mining machinery, and production lines. Of particular importance is its suitability for traction/propulsion systems of water, rail and road.

REFERENCES

1. Prof. Peter Lawrenson, IEE Electronics and Power Journal, February 1983, pp. 144-147.

APPENDIX A UNIVERSITY OF TORONTO TEST REPORT

APPENDIX A

REPORT ON THE

K-MOTOR TESTS

Prepared by:

Department of
Electrical Engineering

University of Toronto

Prepared by

J. A. Cunningham

Dr. S. B. Dewan

Dr. G. R. Slemon

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1. INTRODUCTION

The following report on the performance of the K-motor was prepared by the Department of Electrical Engineering at the University of Toronto on a contractual basis to TranSyt Canada Inc. The test program listed in Appendix A was agreed among the University of Toronto, TranSyt Canada Inc., and Neo-Ken Electrical Industries Ltd.

Chapter 2 of this report describes the physical and electrical parameters of the K-motor system, as well as the specifications for the power supplies required to complete the tests herein described.

A description of the laboratory test system is detailed in Chapter 3.

The procedure for testing the K-motor system and the types of tests performed are discussed in Chapter 4.

The test results obtained on the K-motor system are stated in Chapter 5.

A discussion on the testing limitations of the K-motor system are outlined in Chapter 6.

2. DESCRIPTION AND SPECIFICATIONS OF THE K-MOTOR SYSTEM

2.1 Description of the K-motor System

The K-motor system is an integrated reluctance machine and an electronic power conversion system requiring a separate logic controller.

The reluctance machine is arranged such that stationary stator windings are on the inside of the machine, and the rotor bars are on the outside periphery of the machine. The power take-off point is located in the centre of the machine's axis. This point is mechanically coupled to the peripheral rotor bars, and is brought out of the machine by an axial drive shaft.

The power electronic conversion is accomplished by transistorized choppers. The power electronics design is intended to be powered from three distinct d.c. power sources. The first d.c. power supply or source provides power for motoring output power, winding inductive losses, and the associated resistive, friction and windage losses of the system. The second d.c. power supply or return absorbs the winding inductive losses. The third power supply is required for the transistor's base drive.

The logic controller is powered from a conventional 110 V a.c. source. The controller utilizes rotor shaft position sensor signals to produce synchronized base drive signals required by the power electronic conversion unit. The electronic may be operated in an advance mode (a leading phase shifted base drive) by means of a control mounted switch, after a minimum operating speed has been obtained in the unadvanced mode.

2.2 Specifications of the K-motor System

The physical specifications of the K-motor are stated in Table 2.1 The electrical specifications of the K-motor system power conversion unit are shown in Table 2.2

Number of phases	4
Number of poles per phase	12
Number of coils per pole	2
Number of turns per coil (AWG #16, .2 Ω/coil)	87
Pole dimensions	3.81 x 3.81 cm
Pole pitch	7.62 cm
Rotor/stator air gap	0.381 cm +/- .005 cm
Number of rotor bars	12
Rotor bar dimensions	3.81 x 3.81 x 81.2 cm
Stator outside diameter	29 cm
Iron lamination material	M19

Table 2.1 Physical Specifications of the K-Motor

Input power source	90 V d.c. @ 600A
Output power source	90 V d.c. @ 300A
Base drive power supply	6 V d.c. @ 50A

Table 2.2 Electrical Specifications of the K-Motor Power Conversion Unit

3. LABORATORY TEST SYSTEM FOR TESTING THE K-MOTOR SYSTEM

This chapter describes the laboratory test system required to test the K-motor system.

A block diagram of the laboratory test system is shown in Figure 3.1. The test system is composed of three d.c. power supplies required to power the K-motor system and a d.c. traction motor coupled to a d.c. to a.c. power conversion unit to load the K-motor. The first d.c. power supply or source is obtained from a step-down transformer feeding a rectifier in return feeding an inductive/ capacitive filter. The second d.c. power supply or return is obtained from a variac coupled to a rectifier feeding a parallel resistive capacitance load. This second d.c. power supply does not actually provide power; rather, it provides a stiff d.c. voltage source for regeneration. The third d.c. power source is a conventional 6 V d.c. automobile battery with a parallel battery charger.

Arrangements were made to observe both the instantaneous and average currents and voltages of the first two power supplies; only the average current from the third power supply was monitored.

A standard trolley coach d.c. motor was used as the load for the K-motor system via a mechanical coupling, incorporating torque and speed transducers, to the drive shaft of the K-motor. This d.c. motor was powered from a d.c. to a.c. laboratory power conversion unit incorporating both field and armature voltage control.

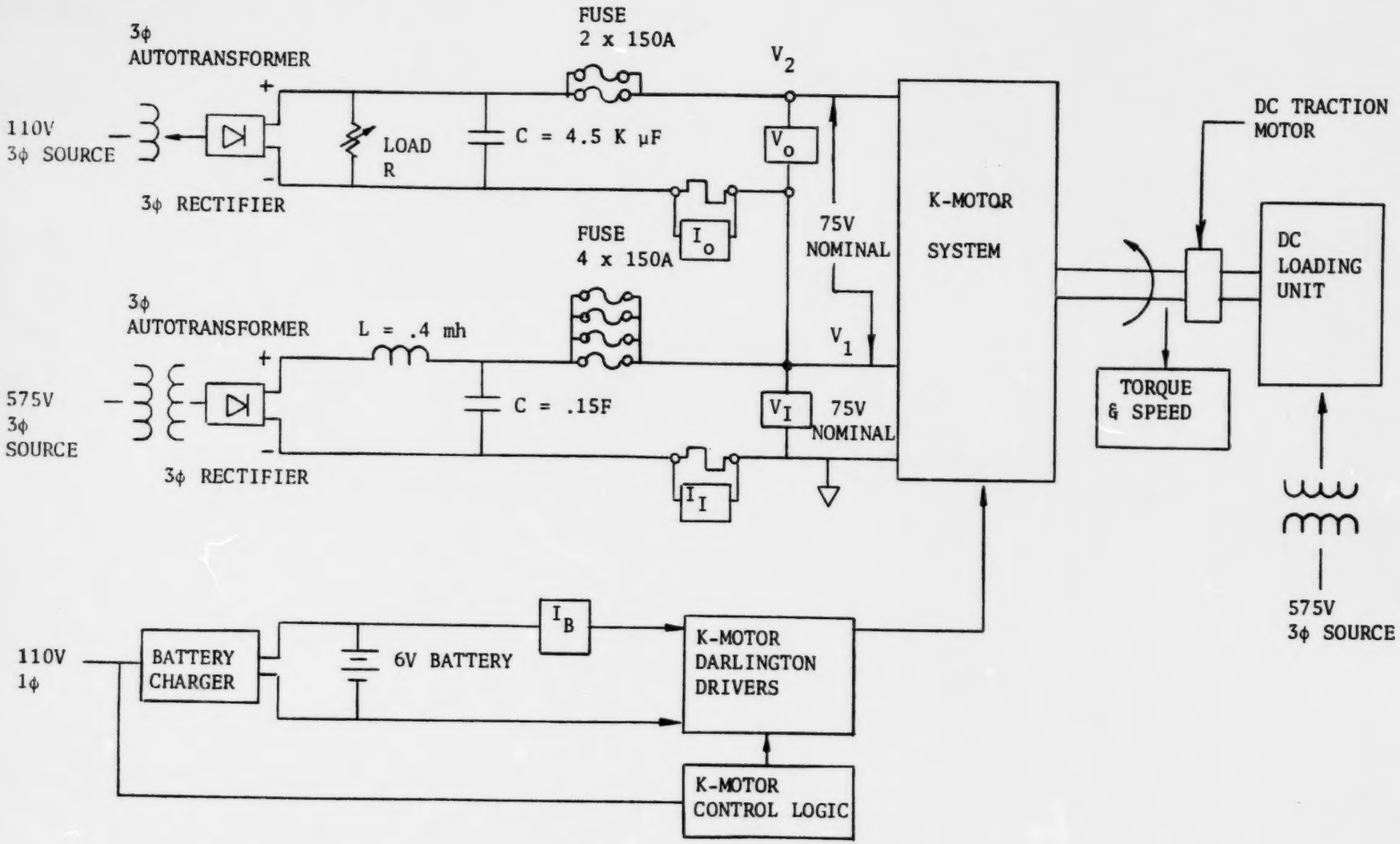


FIGURE 3.1 ARRANGEMENT FOR TESTING THE K-MOTOR SYSTEM.

4. TESTING PROCEDURES AND TEST SPECIFICATIONS

4.1 Testing Procedure

The following procedures were observed during all aspects of the K-motor tests:

(a) All power supplies were energized and adjusted to a predetermined level as specified in Section 4.2.1.

(b) The K-motor controller was started in the unadvanced mode and switched to the advance mode as required by the specified tests in Appendix B.

(c) All phases of the K-motor were energized.

(d) The current limit of the K-motor controller was set at maximum.

(e) The pulse width controls of the K-motor controller was set at maximum for all maximum torque tests.

(f) The temperature of specific coils was monitored to eliminate motor damage.

4.2 Test Specifications

The following are the specifications for the test performed on the K-motor system:

4.2.1 Test Conditions

(a) Source power supply nominal voltage was 75 V d.c.

(b) Return power supply nominal voltage was 75 V d.c.

(c) Advance used above 250 r.p.m.

5. TEST RESULTS

This chapter describes the results obtained from testing the K-motor system.

5.1 Maximum Torque vs. Speed Test Results

The maximum torque T vs. speed curve is shown in Figure 5.1. Figure 5.2 illustrates the input or source power P_{IN} and output or or return power P_{OUT} variation with speed. The total input power PE (source power minus return power)and the mechanical power P_{MECH} variation with speed are shown in Figure 5.3. The efficiency variation with speed is shown in Figure 5.4.

The test data used to create Figures 5.1 through 5.4 are listed in Table 5.1. Table 5.2 lists the test data on the motor coil temperature rise for various speeds at maximum torque for a 5 minute interval. Figure 5.5 illustrates the temperature variation with speed at maximum torque.

Figures 5.6 through 5.12 depict the input and output voltage and current waveforms observed at maximum torque for speeds of 125, 250, 375, 500, 625 and 750 r.p.m.

5.2 Constant Torque vs. Speed Test Results

Constant torque vs. speed test data shown in Table 5.3 was taken at 113 and 56 N.m, since these torque levels could be measured through a wider speed variation of the K-motor system.

Figures 5.13 and 5.14 illustrate the variation with speed of total input power PE and mechanical power P_{MECH} and efficiency respectively at a constant torque of 13 N.m.

Figures 5.15 and 5.16 illustrate the variation with speed of total input power PE and mechanical power P_{MECH} and efficiency respectively at a constant torque of 56 N.m.

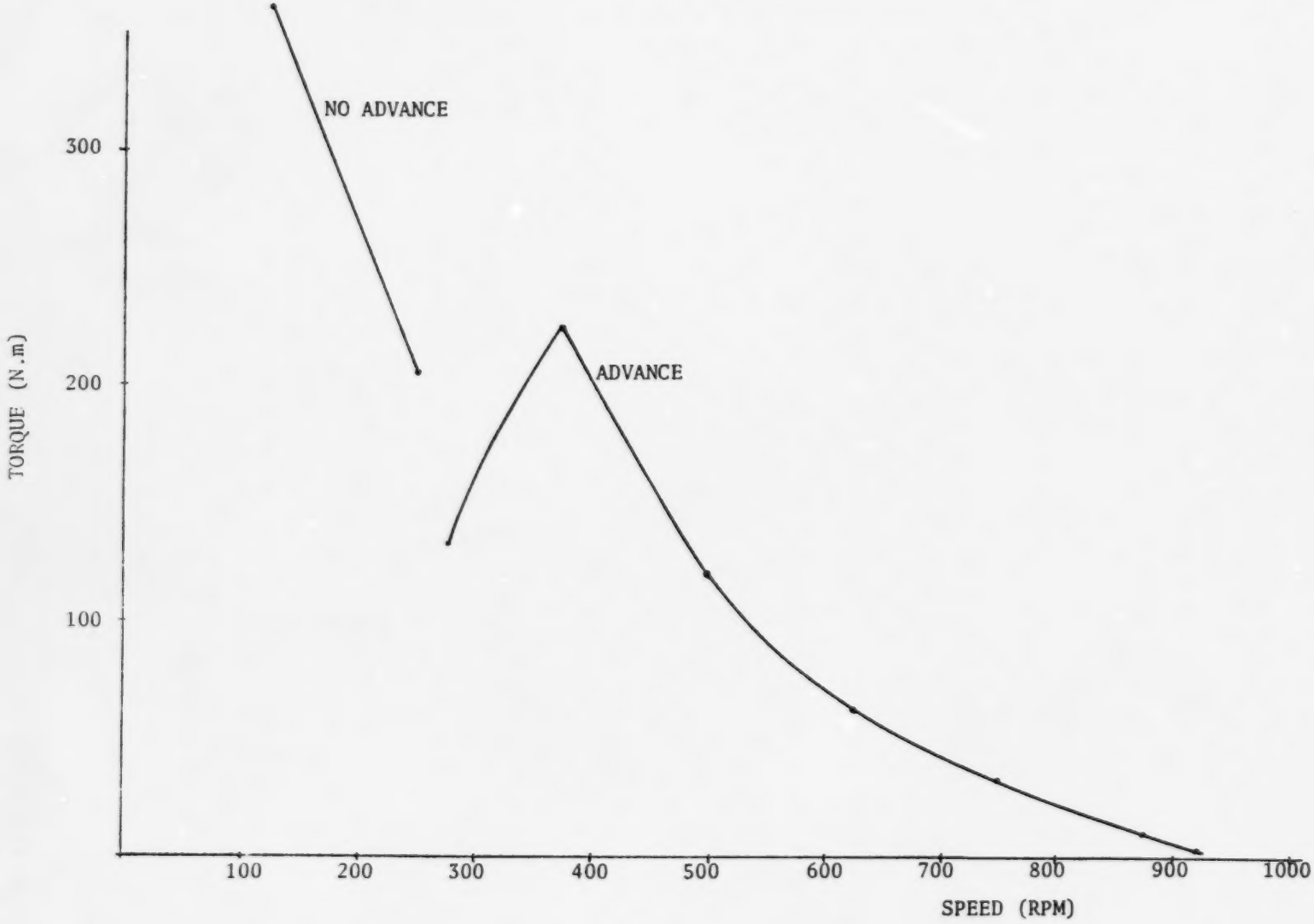


FIGURE 5.1 MAXIMUM TORQUE VS. SPEED.

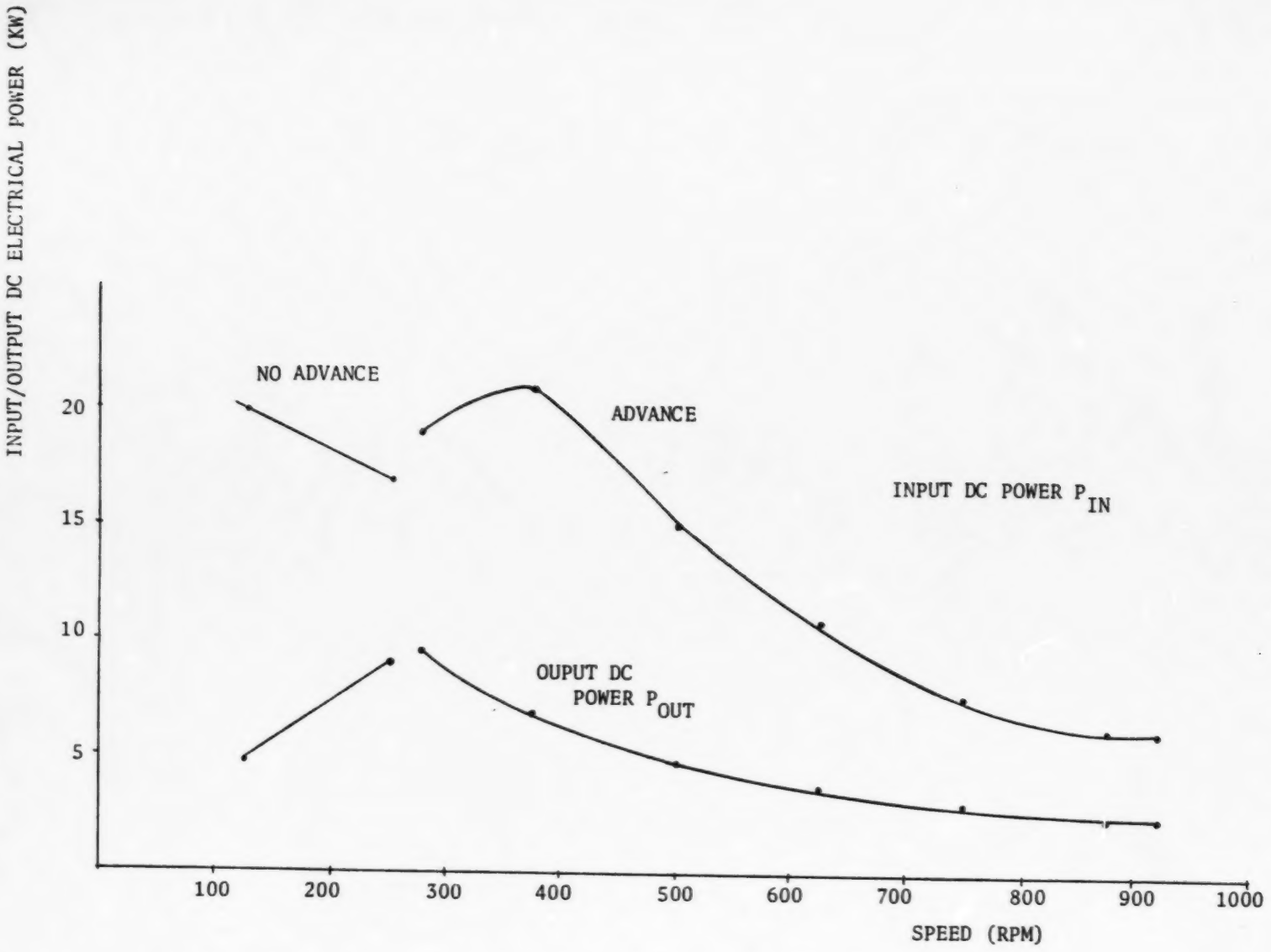


FIGURE 5.2 INPUT AND OUTPUT DC POWER VS. SPEED AT MAXIMUM LOAD.

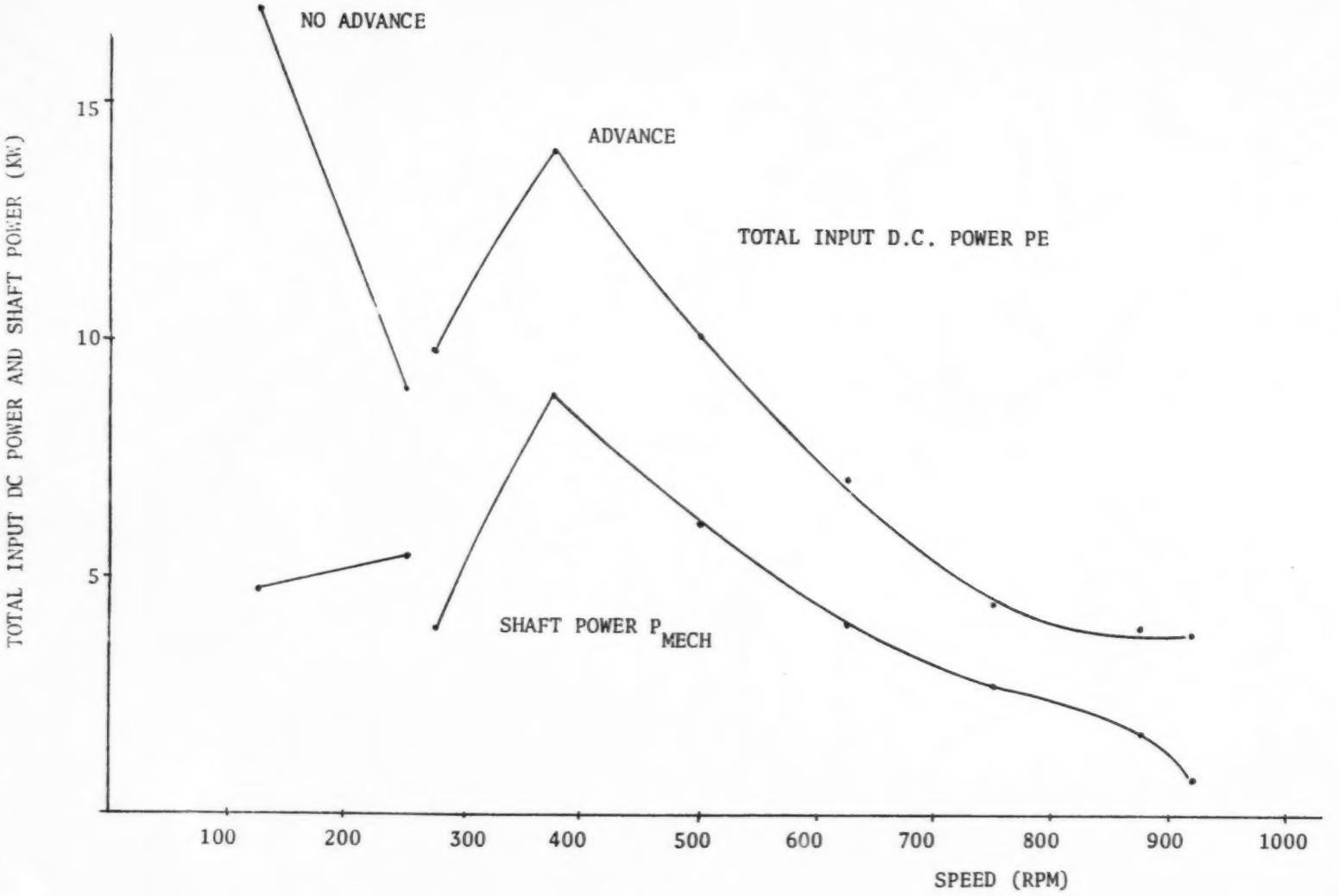


FIGURE 5.3 TOTAL INPUT DC POWER AND SHAFT POWER VS. SPEED AT MAXIMUM LOAD.

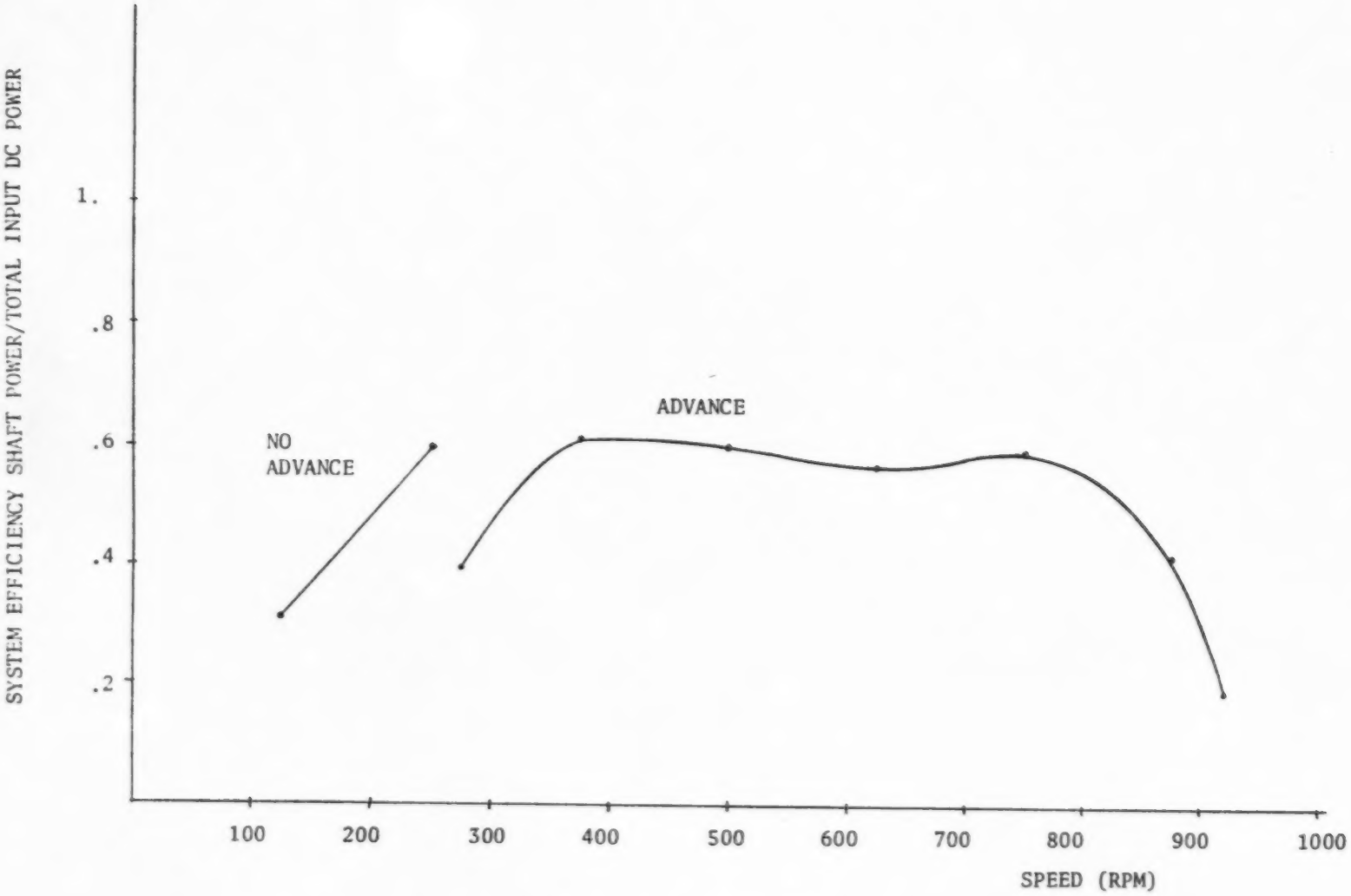


FIGURE 5.4 SYSTEM EFFICIENCY VS. SPEED AT MAXIMUM LOAD.

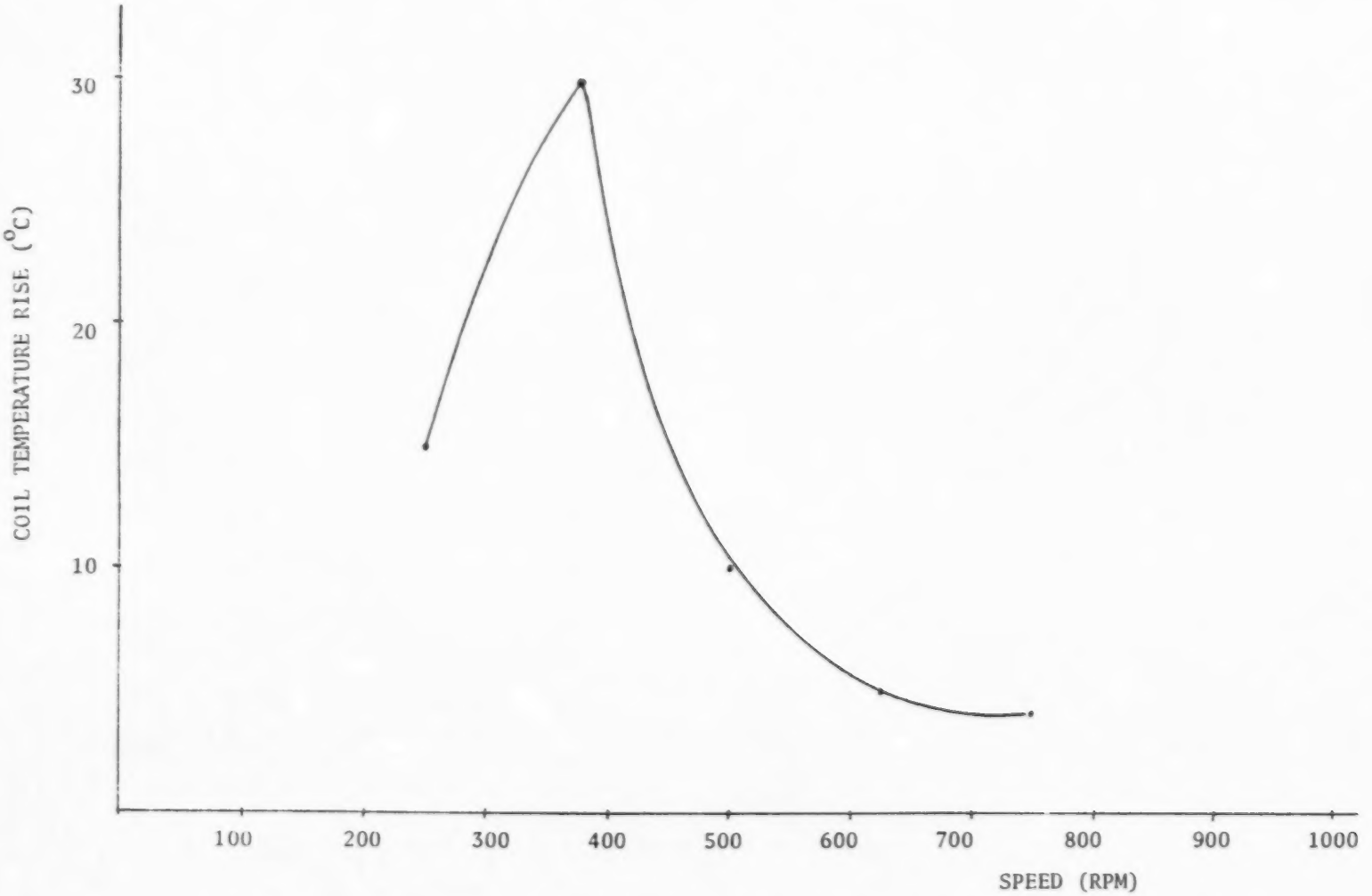


FIGURE 5.5 COIL TEMPERATURE RISE VS. SPEED AT MAXIMUM LOAD FOR 5 MINUTES.

TABLE 5.1

Maximum Torque vs. Speed Test Results

Speed (RPM)	Torque (N.m)	P_{MECH} KW	V_{IN} (V)	I_{IN} (A)	P_{IN} (KW)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (KW)	P_E KW	Eff.	Advance
125	362	4.7	72	280	20.	100	48	4.8	15.	31.	NO
250	207	5.4	74	232	17	82	98	8.0	9.	.60	NO
274	133	3.9	73	260	19	88	105	9.2	9.8	.40	YES
375	226	8.8	73	290	21	105	66	6.9	14.	.62	YES
500	120	6.2	75	195	15	88	54	4.8	10	.61	YES
625	63	4.1	76	140	11	79	48	3.8	7.2	.57	YES
750	34	2.7	77	100	7.7	73	44	3.2	4.5	.60	YES
875	18	1.7	77	85	6.5	70	36	2.5	4.0	.43	YES
920	7.9	.76	80	79	6.3	69	36	2.5	3.8	.20	YES

TABLE 5.2

Coil Temperature Rise at Maximum Torque During

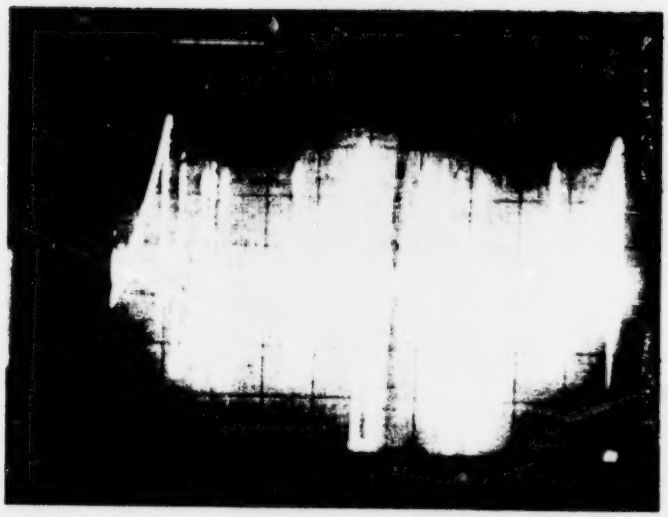
5 Minutes of Operation on Coils R1 and R4

Speed (RPM)	ΔT (^{o}C)
250	15
375	30
500	10
625	5
750	4

TABLE 5.3

Constant Torque vs. Speed Test Results

Speed (RPM)	Torque (N.m)	P_{MECH} KW	V_{IN} (V)	I_{IN} (A)	P_{IN} (KW)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (KW)	P_E KW	Eff.	Advance
125	113	1.5	77	105	8.1	81	56	4.5	3.6	.42	NO
250	113	2.9	75	165	12	98	64	6.3	6.1	.48	NO
250	113	2.9	75	100	7.5	70	46	3.2	4.3	.67	YES
375	113	4.4	75	140	11	72	50	3.6	7.4	.59	YES
500	113	5.9	75	185	14	80	56	4.5	9.5	.62	YES
125	56	.73	78	55	4.3	68	40	2.7	1.6	.46	NO
250	56	1.5	76	135	10	99	66	6.5	3.5	.43	NO
250	56	1.5	76	60	4.6	66	34	2.2	2.4	.63	YES
375	56	2.2	76	75	5.7	67	38	2.5	3.2	.69	YES
500	56	2.9	78	95	7.4	70	42	2.9	4.5	.64	YES
625	56	3.6	77	120	9.2	73	48	3.5	5.7	.63	YES

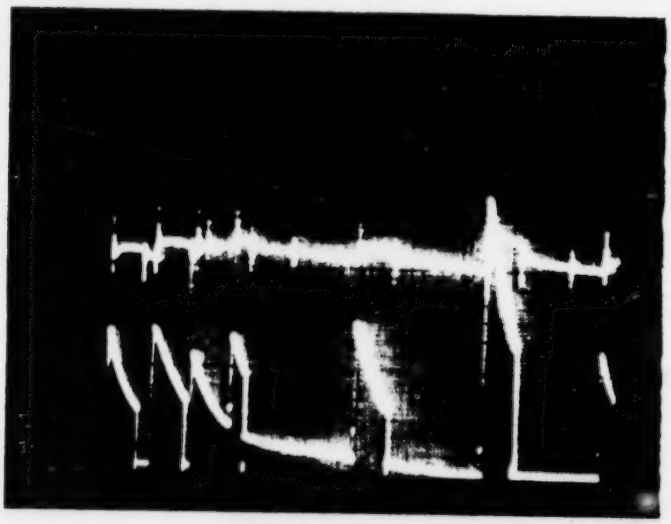


V_{IN}: 20 V/div

I_{IN}: 100A/div

Zero, 2 ms/div

Input Voltage and Current Waveforms V_{IN} and I_{IN}.



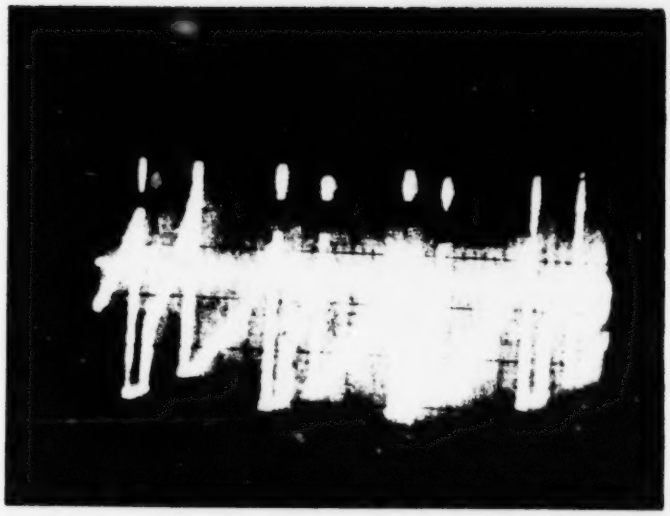
V_{OUT}: 20 V/div

I_{OUT}: 100A/div

Zero, 1 ms/div

Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.6 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 125 RPM (NO ADVANCE).

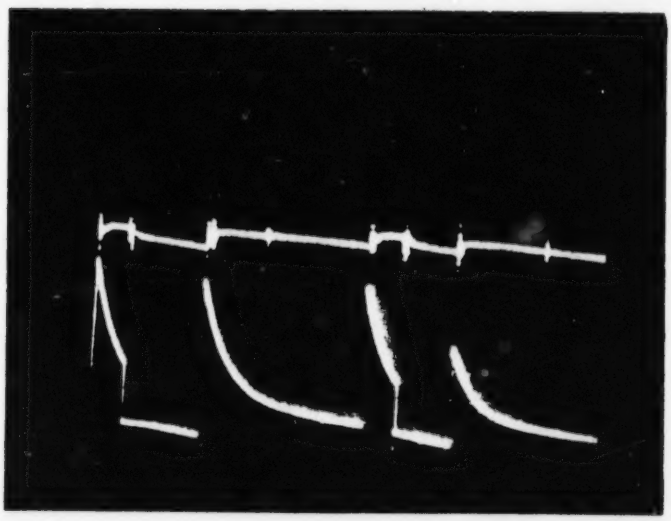


V_{IN}: 20 V/div

I_{IN}: 100A/div

Zero, 2 ms/div

Input Voltage and Current Waveforms V_{IN} and I_{IN}.



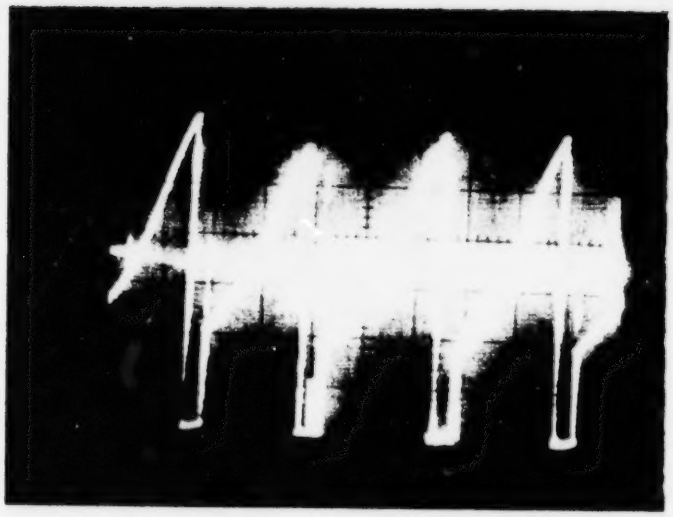
V_{OUT}: 20 V/div

I_{OUT}: 100A/div

Zero, 1 ms/div

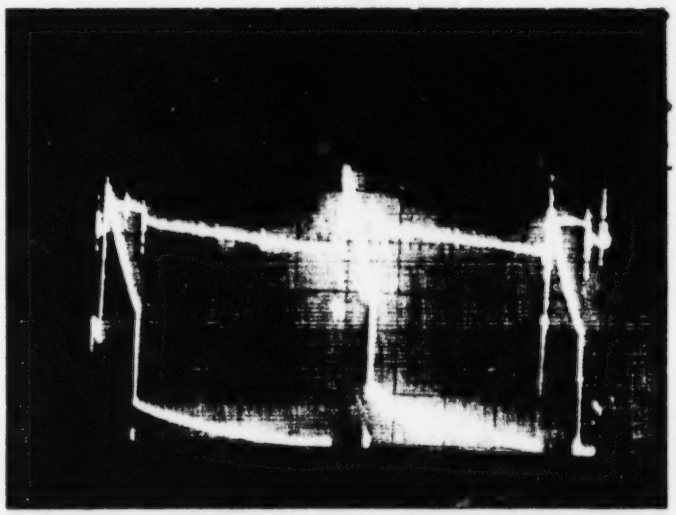
Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.7 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 250 RPM (NO ADVANCE).



V_{IN}: 20 V/div
I_{IN}: 100A/div
Zero, 2 ms/div

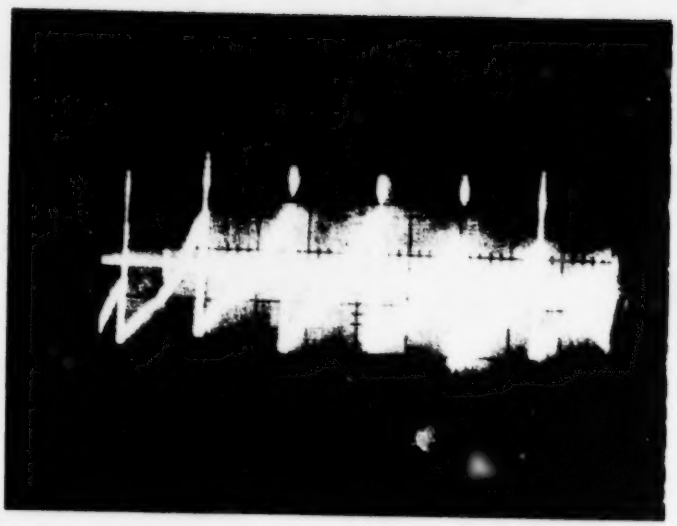
Input Voltage and Current Waveform V_{IN} and I_{IN}.



V_{OUT}: 20V/div
I_{OUT}: 100A/div
Zero, 1 ms/div

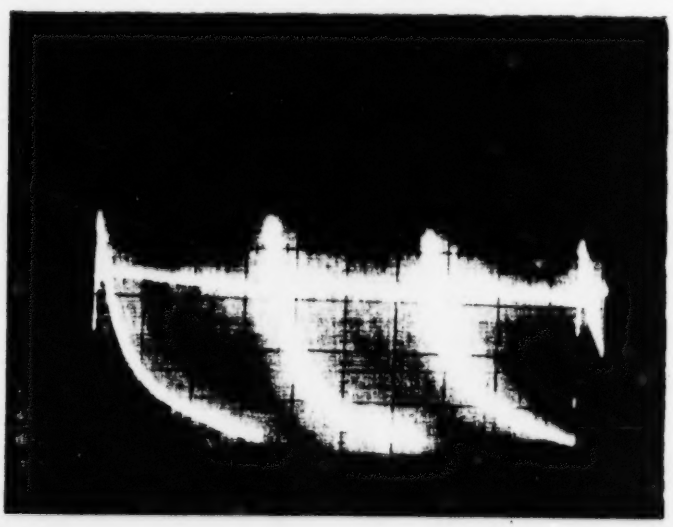
Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.8 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 250 RPM.



V_{IN}: 20 V/div
I_{IN}: 100A/div
Zero, 2 ms/div

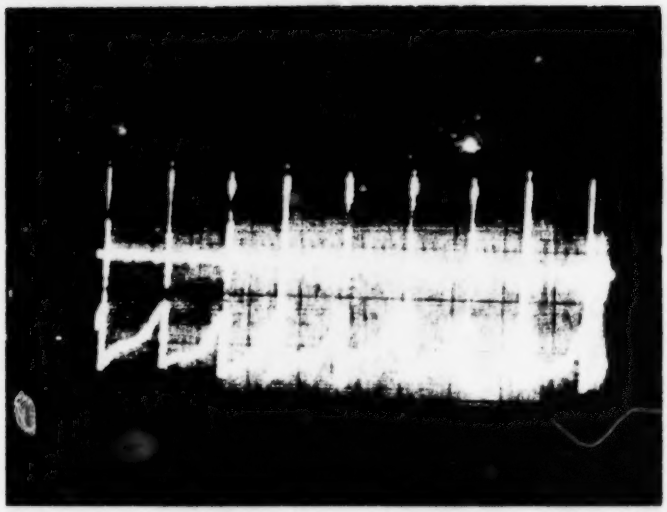
Input Voltage and Current Waveforms V_{IN} and I_{IN}.



V_{OUT}: 20 V/div
I_{OUT}: 50A/div
Zero, 1 ms/div

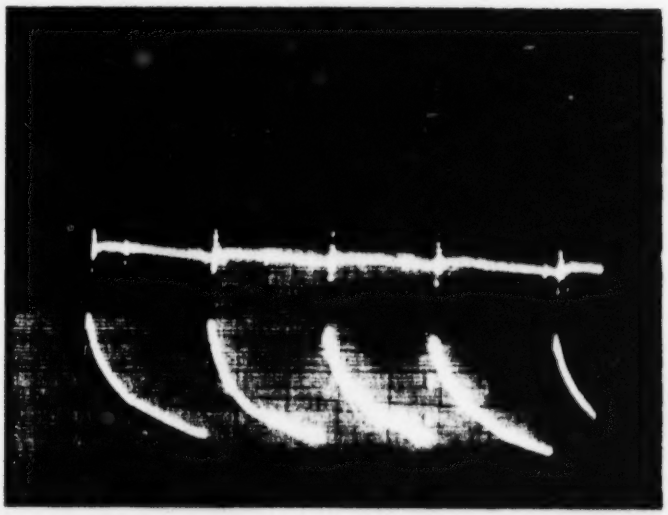
Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.9 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 375 RPM.



V_{IN}: 20 V/div
I_{IN}: 100A/div
Zero, 2 ms/div

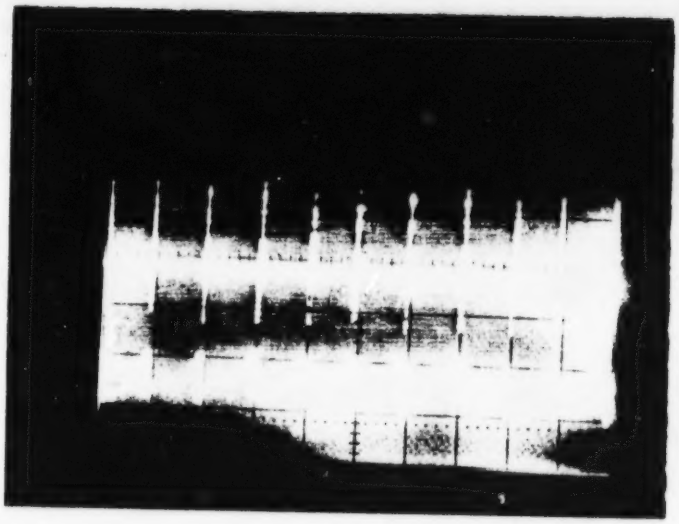
Input Voltage and Current Waveforms V_{IN} and I_{IN}.



V_{OUT}: 20 V/div
I_{OUT}: 50A/div
Zero, 1 ms/div

Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.10 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 500 RPM.

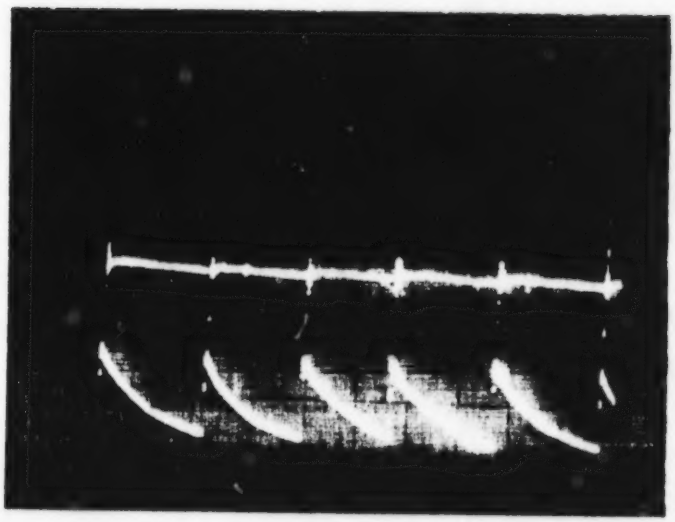


V_{IN}: 20 V/div

I_{IN}: 100A/div

Zero, 2 ms/div

Input Voltage and Current Waveforms V_{IN} and I_{IN}.



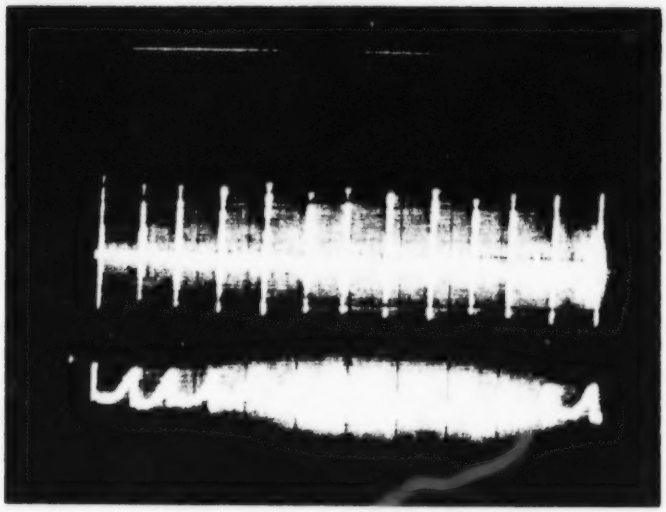
V_{OUT}: 20 V/div

I_{OUT}: 50A/div

Zero, 1 ms/div

Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.11 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 625 RPM.

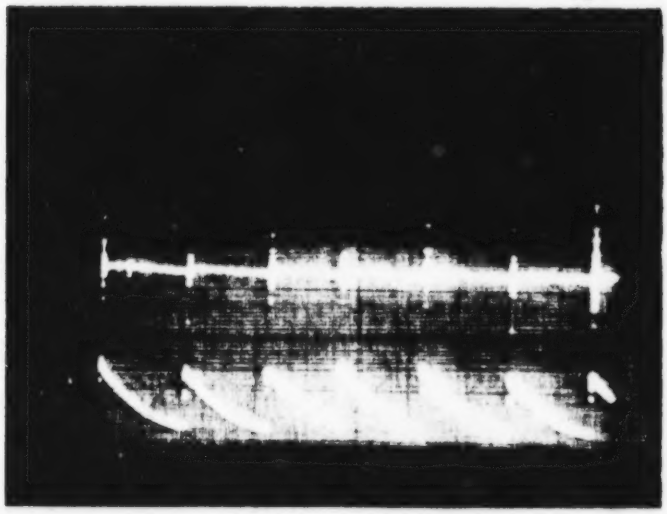


V_{IN}: 20 V/div

I_{IN}: 100 A/div

Zero, 2 ms/div

Input Voltage and Current Waveforms V_{IN} and I_{IN}.



V_{OUT}: 20 V/div

I_{OUT}: 50A/div

Zero, 1 ms/div

Output Voltage and Current Waveforms V_{OUT} and I_{OUT}.

FIGURE 5.12 INPUT AND OUTPUT VOLTAGE AND CURRENT WAVEFORMS OBSERVED AT MAXIMUM TORQUE WITH A SPEED OF 750 RPM.

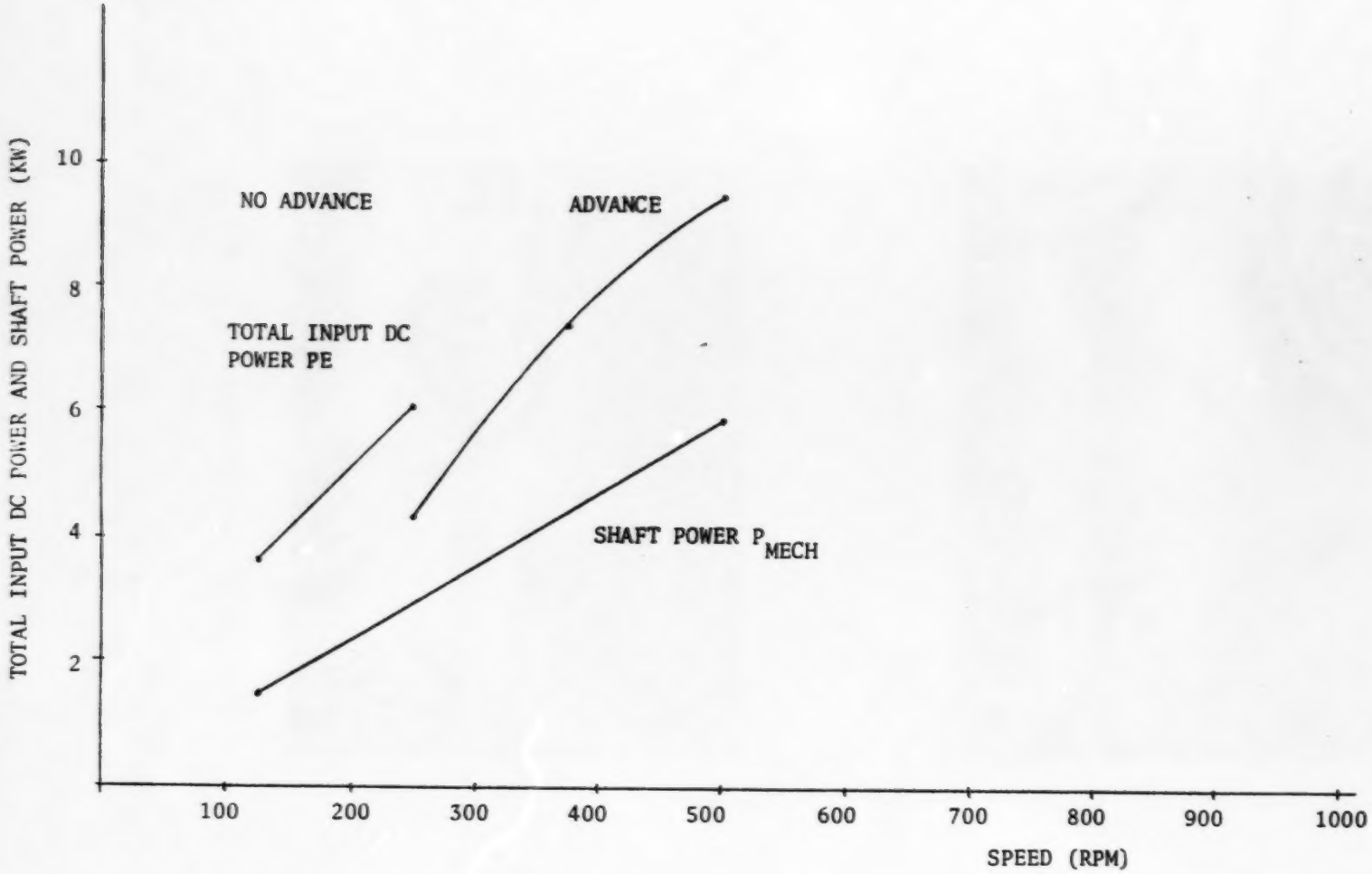


FIGURE 5.13 TOTAL INPUT DC POWER AND SHAFT POWER VS. SPEED AT A CONSTANT TORQUE OF 113 N.m.

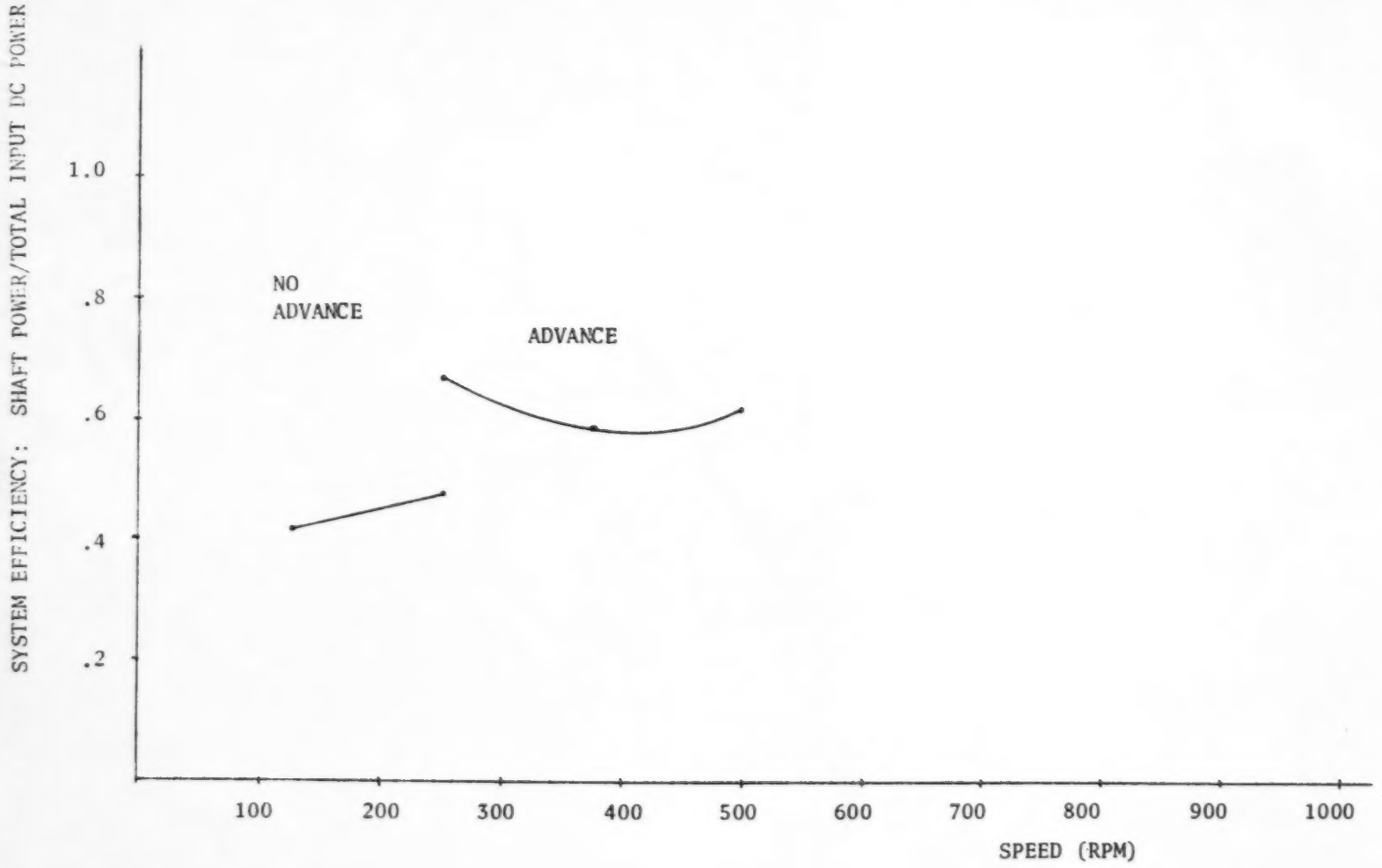


FIGURE 5.14 SYSTEM EFFICIENCY VS. SPEED AT A CONSTANT TORQUE OF 113 N.m.

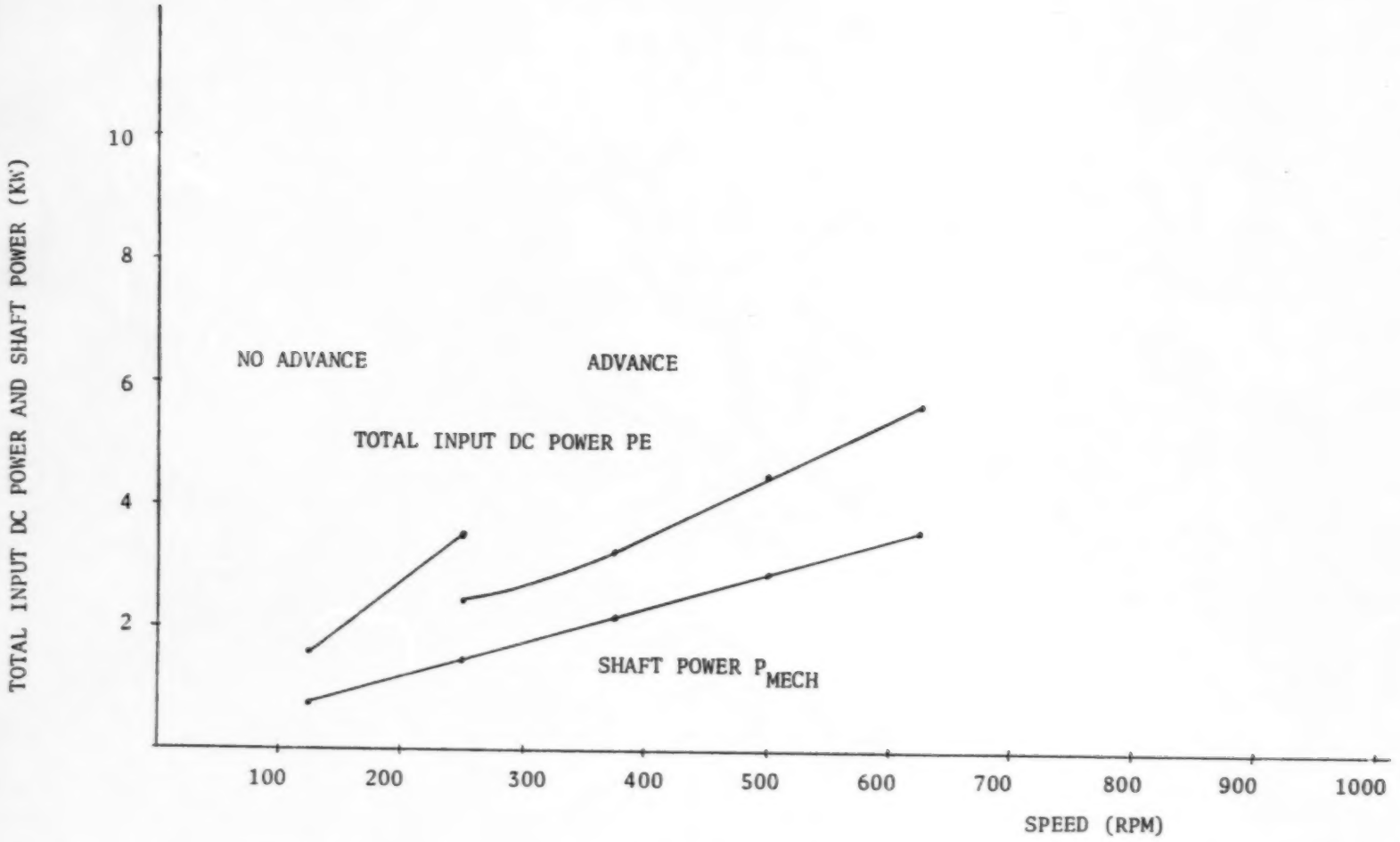


FIGURE 5.15 TOTAL INPUT DC POWER AND SHAFT POWER VS. SPEED AT A CONSTANT TORQUE OF 56 N.m.

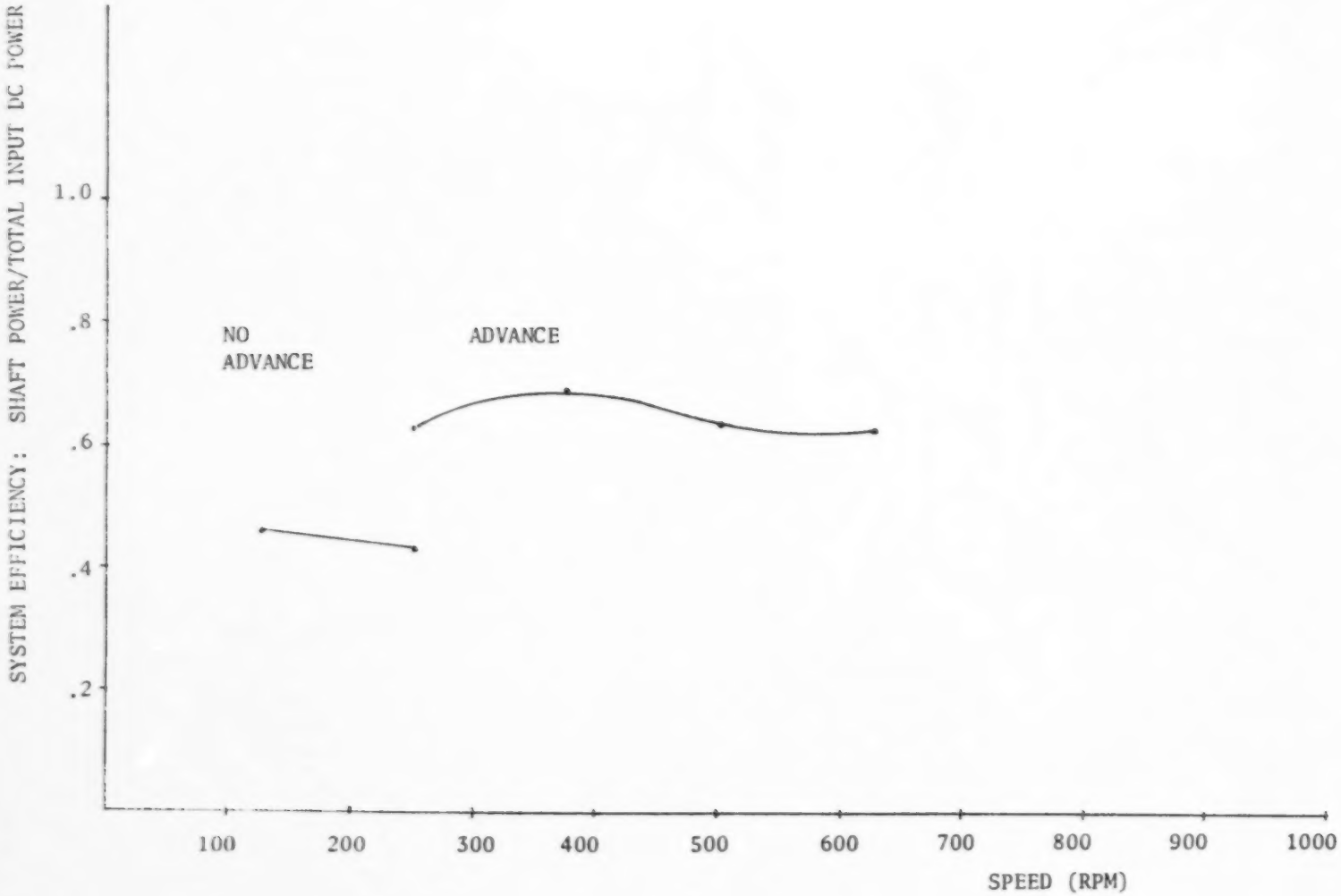


FIGURE 5.16 SYSTEM EFFICIENCY VS. SPEED AT A CONSTANT TORQUE OF 56 N.m.

6. TEST LIMITATIONS OF THE K-MOTOR SYSTEM

This chapter discusses the test limitations necessitated by the K-motor system.

6.1 Current Limitations

The K-motor controller maximum current limit was set at 600 Ap; as such, the actual motor stall torque could not be measured.

6.2 K-Motor Controller Limitations

The K-motor controller had several limitations. Because the pulse width frequency was random, the filtering required for the main power supply (or source) was large. The advance circuitry, which was not automatic necessitating greater operator care, did not achieve the required advance firing to maximize torque throughout the operating range of its use as depicted in Figure 5.4.

6.3 K-Motor Limitations

A locked drive shaft test on the K-motor could not be achieved because of the elasticity between the drive shaft and the rotor bars. This precluded test 4.2.2.3 and all zero speed measurements.

7. CONCLUSIONS

All of the basic requirements detailed in the Appendix have been accomplished. All of the test results could not be obtained because of the limitations of the K-motor design as detailed in Chapter 6.

From our experience with motors in variable speed applications and the K-motor tests, it is our considered opinion that pursuing any further development of the K-motor is not justified for the following reasons:

(a) The optimum torque per unit volume obtainable with a K-motor is at best half that of an induction or d.c. motor. This is because the K-motor operates on the reluctance motor principle and stator has concentrated windings.

(b) The power electronics control required to obtain an acceptable drive system performance is likely to be at least 50% more complex than an inverter required to obtain variable speed drive on an induction motor. This is because more power switches are required and the input filtering problems with the K-motor system are significantly more complex.

(c) From basic fundamentals of motors and power conditioning, we cannot visualize any application where this motor system would have any advantages over any conventional system.

APPENDIX A

1. PROPOSED K-MOTOR TESTS

The following are the required tests for the K-motor. This test program has been agreed between J. A. Cunningham, University of Toronto (416) 978-8673; R. Kenwell, Neo-Ken Industries (403) 438-0492; W. M. Mizera, TranSyt Canada (416) 226-9112.

(a) Determine the maximum torque vs. speed curve for 0-1000 RPM in 25% speed tests.

- Observe: V input, I input, V output, I output; average d.c. , waveforms.
- Determine: Pdc input, Pdc output, Pmech output efficiency.
- Monitor: ΔT on selective pole coils for a predetermined run time.

(b) Repeat step (a) for 50% and 25% of maximum stall torque through 0-1000 RPM in 25% speed steps; without doing temperature measurements.

(c) Determine the torque vs. pole position profile for zero speed at 50 Adc.

2. TEST CONDITIONS

(a) Vdc 75 V nominal within the limits of the K-motor controller for the input voltage, and 75 V nominal for output.

(b) Advance used above 300 RPM, and not used below 300 RPM.